JATROPHA CURCAS OIL AS A BIOBASED REJUVENATING AGENT FOR RECLAIMED ASPHALT MIXTURES

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DEDICATION

To my esteemed and cherished family, friends and
all those who have contributed to this project
for their continuous support, encouragement, and motivation
I couldn't have done this without your support

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ABSTRACT

Recycled asphalt pavement (RAP) is the most effective way to reduce the use of fresh asphalt binder and to consider its application at a higher percentage for the preparation of Hot Mix Asphalt (HMA). Use of RAP in HMA helps to lower the consumption of virgin aggregates and binder, consequently the construction cost and conservation of energy. This research investigates the performance of *Jatropha curcas* oil (JCO) as a bio-based rejuvenating agent for reclaimed asphalt binders and mixtures. The optimum JCO content was determined through asphalt binder test. A total of 4% JCO by mass of asphalt binder (40% RAP + 60% virgin binder) was incorporated into the binder and mixtures. The effects of JCO on asphalt binder and mixture were investigated via physical properties test, bleeding test, diffusion test, rheological properties, chemical properties and mixtures performance test, respectively. The test results show that the incorporation of JCO with virgin binder decreased the viscosity and improved the visco-elastic properties of the rejuvenated binder. Viscosity reduction was also observed when JCO incorporated with reclaimed asphalt binder. Hence, this indicates the potential to reduce the production temperature of the RAP mixture. From the rheological master curves, the addition of JCO decreased the complex modulus values compared to the virgin binder sample. Atomic force microscopy (AFM) and Fourier Transform infrared (FTIR) test results showed the ability of JCO to reduce the effects of aging. The performance of recycled asphalt mixtures was improved in terms of workability, while reducing the fuel requirement and GHG emissions gas released during the production of the mixtures. Moreover, the addition of JCO improves the adhesion between the recycled binder and aggregate, therefore, providing more resistance to moisture damage.

ABSTRAK

Turapan asphalt dikitarsemula (RAP) adalah kaedah yang paling berkesan untuk mengurangkan pengguna bahan pengikat asphalt yang baharu dan untuk mempertimbangkan penggunaannya pada peratusan yang lebih tinggi dalam penyediaan Campuran Asfalt Panas (HMA). Penggunaan RAP dalam HMA akan membantu untuk mengurangkan penggunaan agregat baharu dan bahan pengikat baharu, dan seterusnya mengurangkan kos pembinaan dan meningkatkan penjimatan tenaga. Kajian ini menyelidik prestasi minyak *Jatropha curcas* (JCO) sebagai bahan atau agen bio-rejuvenasi (rejuvenation) untuk bahan pengikat dan campuran RAP. Kandungan JCO yang optimum ditentukan melalui ujian bahan pengikat asphalt. Sejumlah 4% JCO yang disukat dari jisim bahan pengikat asphalt (40% RAP + 60% bahan pengikat baharu) telah digabungkan atau dicampurkan di dalam bahan pengikat dan bahan campuran. Kesan dari JCO ke atas bahan pengikat asphalt dan campuran telah diselidik melalui ujian ciri-ciri fizikal, ujian penjujuhan, ujian peresapan, ujian ciri-ciri reologi, ujian ciri-ciri kimia dan ujian prestasi bahan campuran. Keputusan ujian menunjukkan bahawa penggunaan JCO dengan bahan pengikat yang baharu telah mengurangkan kelikatan dan menambahbaiki ciri-ciri visco-elastic bahan pengikat yang direjuvenasikan. Pengurangan ciri-ciri kelikatan juga diperhatikan apabila JCO telah dicampurkan dengan bahan pengikat yang dikitarsemula. Oleh itu, ini menunjukkan terdapat potensi untuk mengurangkan suhu dalam penghasilan bahan campuran RAP. Daripada lengkuk utama reologikal pula, penambahan JCO telah mengurangkan nilai complex modulus berbanding dengan nilai yang dihasilkan oleh bahan pengikat baharu. Keputusan dari ujian Atomic Force Microscopy (AFM) dan Fourier Transform Infrared (FTIR) menunjukkan keupayaan JCO untuk mengurangkan kesan *aging* atau penuaan. Prestasi bahan campuran asphalt dikitarsemula telah ditambahbaiki dari aspek *workability* atau kebolehkerjaannya, di samping mengurangkan keperluan bahan api dan pengeluaran gas GHG yang terhasil semasa proses pembuatan bahan campuran. Lagipun, penambahan JCO telah menambahbaiki kebolehlekatan di antara bahan pengikat yang dikitarsemula dengan bahan agregat seterusnya memberikan lebih kekuatan menahan dari berlakunya kerosakan kelembapan.

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LIST OF SYMBOLS AND ABBREVIATIONS

F	Recovered angle
G*/sin δ	Superpave™ rutting factor
G*	Complex shear modulus
δ	Phase angle
A	Thermal diffusivity
FT_U	High failure temperatures of unaged asphalt binder
E	Cumulative micro-strain
FT_S	High failure temperatures of short-term-aged asphalt binder
G'	Elastic component or storage modulus
G''	Viscous component or loss modulus
J_{nr}	Creep compliance
M_R	Resilient modulus
ω	Average angular recovery speed
$[\nabla M_R]_A$	Rate of aging effect on resilient modulus due to long-term aging condition at 25℃
$[\nabla M_R]_T$	Rate of test temperature effect on resilient modulus
ΔM_R	Difference in resilient modulus
∇M_R	Resilient modulus gradient
γ	Ratio of the strain
σ	Constant applied load
PI	Penetration Index
R	Percentage recovery
$RAP_{binder,mix}$	Percentage of RAP binder in the total binder of a mixture
RAP_{agg}	Percentage of RAP aggregate in the mixture

RAP_{actual}	Percentage of actual RAP including RAP binder added in the mixture
RAP_{bc}	Binder content of RAP
G_{sb}	Bulk specific gravity of aggregate
G_b	Specific gravity of asphalt binder
G_{se}	Effective specific gravity of aggregate
G_{mb}	Specific gravity of aggregate
G_{mm}	Theoretical maximum specific gravity
T	Temperature
Q	Total energy
G_{sb}	Bulk specific gravity of aggregate
S.P	Softening point
α	Level of significance
β	Regression coefficient for x
δ	Phase angle ε - sinusoidal strain
$\varepsilon 3600$	Strain at 3600th cycle
$\varepsilon 1200$	Strain at 1200th cycle
η	Viscosity
σ	Amplitude stress
P	Probability value
S	Creep stiffness
X	Independent variable
Y	Dependent variable
AV	Air void
ANOVA	One-way analysis of variance
AV	Air void
AR	Aging ratio
ARRA	Asphalt recycling and reclaimed association
ASTM	American society for testing and materials
ATR	Attenuated total reflection
BS	British standard
COV	Coefficient of variance
CEI	Compaction energy index

CO_2	Carbon dioxide
CO	Carbon monoxide
DSC	Differential scanning calorimetry
DP	Dust proportion
EPA	Environmental protection agency
DSR	Dynamic shear rheometer
FTIR	Fourier transform infrared
FHWA	Federal highway administration
GHG	Greenhouse gas
Gmm	Maximum specific gravity
Ho	Null hypothesis
HMA	Hot mix asphalt
HSD	Honestly significant difference
IDT	Indirect tensile
ITS	Indirect tensile strength
JKR	Jabatan Kerja Raya (Malaysian public works department)
LVDT	Linear variable displacement transducers
MR	Resilient modulus
NCAT	National center for asphalt technology
OBC	Optimum binder content
PAV	Pressure aging vessel
PI	Penetration index
PG	Performance grade
PVN	Penetration viscosity number
R^2	Coefficient of determination
R&B	Ring and ball temperature
RAP	Reclaimed asphalt pavement
RTFO	Rolling thin Film oven
RV	Rotational viscometer
SGC	Superpave gyratory compactor
SHRP	Strategic highway research program
TSR	Tensile strength ratio
UTM	Universal testing machine
UV	Ultra violet

VFA	Void filled with asphalt
VMA	Void in mineral aggregate
VTM	Void in total mixture

CHAPTER 1

INTRODUCTION

1.1 Background of study

Asphalt binder is the glue that binds aggregates together due to its complex, viscoelastic, rheological and non-crystalline material (black or dark brown). This material exhibits adhesive and water-proof characteristics, with its microwave permittivity (dielectric constant, ε') value ranging from 2 – 7 depending on the grade of the asphalt binder and asphaltene content of distilled products obtained from the oil refining process. Today, asphalt binder has become the most commonly used construction material for road construction in the world, constituting up to 90 percent of global highways. Asphalt binder is a product that is obtained from the oil refining process. The volatility of the world's oil market has pushed oil prices, and as a result, the price of asphalt binder varies with an increase in the cost of petroleum. The price of petroleum, on the other hand, is continuously increasing as the consumption level spikes (Aziz *et al.,* 2015; Bioenergy, 2015).

From the analysis of the January 2011 Global Industry Market Report, 118.4 million metric tons of asphalt would have reached the global asphalt market by 2015 (Peralta *et al.,* 2012). The asphalt paving industry accounts for the most significant end-user market segment of asphalt. Asphalt binder supplies are shrinking, while the demand for it is increasing rapidly and petroleum oil reserves are becoming depleted. This, in turn, has led to an increase in the price of asphalt.

For this reason, as well as increased environmental concerns and awareness of depleting natural resources, the use of recycled asphalt materials has received increased recognition in the asphalt industry (Peralta *et al.,* 2012). The Recycling of asphalt mixtures has been carried out for several years, but most of these materials have been used as lower-class materials such as a fill or blinding material, in the construction of low-trafficked roads and other paved areas. The reason behind this is that RAP materials do not have fixed physical characteristics and its properties will vary with the RAP source and with time. To overcome this lack of uniformity, road agencies have put usage limits and measures in place to maintain the quality and consistency of asphalt mixes containing RAP.

The economic and environmental benefits of RAP use can be further increased if higher quantities are used. Considering material and construction costs, it has been estimated that the use of RAP provides savings ranging from 14% to 34% for RAP content varying between 20% and 50% (Daniel & Lachance, 2005). While contractors are willing to use higher percentages of RAP, a more extensive mix design procedure is required for high RAP mixes as there are concerns that high recycled material content significantly reduces the performance of asphalt pavements. RAP binders are stiffer than virgin binders, which makes them more susceptible to various modes of cracking. Such cracking is more likely to occur as the percentage of RAP binder increases. Furthermore, the lack of understanding towards the effect of the recycling agent (rejuvenators) on pavement performance can act as a barrier to using higher RAP contents in HMA mixes, thereby creating a need for clear mix design guidelines and material characterization as well as detailed manufacturing and construction practices (You *et al.,* 2011). The main functions of an asphalt rejuvenating agent are as follows (Brownfield, 2010):

a) To introduce maltenes and saturates (light fractions) to the aged asphalt binder
b) To soften the stiffness of oxidized asphalt pavement and flux with the asphalt binder
c) To extend the life expectancy or service life of the pavement

For this application, either the rejuvenator is blended first with unaged asphalt binder before mixing with the aged material, or the rejuvenator is mixed first with the dry aged aggregates before unaged asphalt binder is added.

Research has been done by adding rejuvenators to renew the properties of old asphalt pavement. The asphalt binder properties can be improved to restore the original ratio of asphaltenes to maltenes and compensate for the hardening effect, thereby making the high RAP mixture more workable. Some rejuvenators have proven to have

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